ENVISAT
MERIS, GOMOS, ASAR &
MIPAS IN-ORBIT MISPOINTING
REPORT[1]

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[1] D:Reports/Pointing Report.doc

1.0 INTRODUCTION

This note supplies the in-orbit pointing characterisation results of the MERIS, GOMOS, ASAR and MIPAS instruments, derived using algorithms and data resident within the IECF and MICAL.

The goals of post-launch mispointing estimation were twofold:

1. Demonstrate compliance to pre-launch pointing requirements

2. Improve post-launch pointing knowledge, and, if required, incorporate the results into the on-ground processing software

It is emphasised that it's the pointing direction of the instrument's line of sight (or electrical boresight) is characterised and reported, which is subject to AOCS errors, platform structural distortions, satellite level instrument alignment errors, instrument internal alignment errors, instrument thermal distortions and mechanism pointing errors (GOMOS & MIPAS). Since most of these errors are on instrument level a spread in results from instrument to instrument is to be expected.

For all instruments, mispointing is assumed to have a constant and variable part. The constant (or bias) is assumed to be unchanging, while the varying part is directly dependent on orbital position, and is modelled as a series of harmonics.

In some cases instrument measurements are not directly susceptible to mispointing and therefore complete Roll, Pitch and Yaw characterisation is not possible. Further, due to target (measurement) limitations it is not possible to obtain separate bias and harmonic errors and only combined estimates can be obtained. In particular this is true for MERIS, where ground targets are grouped closely together on the earth's surface. The following table lists the relationship between the instrument and the mispointing axes characterised.

INSTRUMENT	CHARACTERISED AXES
ASAR	Z-Axis (Yaw) X-Axis (Pitch)
GOMOS	Z-Axis (Yaw) Y-Axis (Roll) X-Axis (Pitch)
MERIS	Z-Axis (Yaw) Y-Axis (Roll) X-Axis (Pitch)
MIPAS	Y-Axis (Roll) X-Axis (Pitch)

Fundamentally, instrument mispointing is determined by calculating the difference between where an instrument is actually looking to where it should be looking, and relating this difference to satellite level Roll, Pitch and Yaw attitude errors. ASAR doppler measurements are affected by Pitch and Yaw errors and therefore instrument mispointing is directly observable. GOMOS has SFA telemetry which can be used to determine the IFOV look direction, while MERIS, which is an earth viewing instrument, uses measurements derived from on-ground targets. Finally MIPAS calculates the time of star crossings to determine its mispointing.

2.0 DOCUMENTATION

R1: ENVISAT 1 ASAR Antenna FM Alignment Report, PO-RP-DOR-SR-0300

R2: Envisat Mission and Payload Budgets Document, PO-RP-DOR-PL-0056

R3: The IRISH GRID. A description of the Co-ordinate Reference System used in Ireland, OSI

R4: Transformation between The IRISH GRID and the GPS co-ordinate Reference Frame, WGS84/ETRF89, OSI.

3.0 MISPOINTING RESULTS SUMMARY

The following table gives the in-orbit mispointing estimates, against pre-launch budget and specification values.

INSTRUMENT	IN-ORBIT MISPOINTING (deg.)	PRE-LAUNCH BUDGET (deg)	PRE-LAUNCH SPECIFICATION (deg)
MERIS Note: 1	**Roll** = 0.0251 **Pitch** = -0.0022 **Yaw** = 0.0247	**Roll** = 0.0295 (Equivalent to a **Total** **Pitch** = 0.041 **Radial** error of 1205m) **Yaw** = 0.0333	**Total Radial** < 2000m
ASAR Notes: 2,3,4,5	**Elevation** = Not Estim. **Azimuth** = -0.0174 **Normal** = 0.0015	**Elevation** = 0.0298 **Azimuth** = 0.0612 **Normal** = 0.0658	**Elevation** = 0.1048 **Azimuth** = 0.1424 **Normal** = 0.6127
MIPAS Note: 6	**Elevation Rear** = 0.025 **Elevation Side** = TBD	**Elevation Rear** = 0.0926 **Elevation Side** = 0.0881	**El. Rear** = 0.052 **El Side** = 0.052
GOMOS Note:7	**Roll** = 0.008 **Pitch** = 0.016 **Yaw** = -0.0490 The above generates a **Cone Error** = 0.052	**Roll** = 0.0713 **Pitch** = 0.0769 **Cone Error** = 0.1048	**Cone Error** = 0.2740

Notes:

1) *Pre-Launch Specification and budget values taken from R2*
2) *Mispointing table results are given for bias estimates only. Pitch and Yaw harmonics (in satellite axes) are -0.0002 and 0.020 deg. respectively.*
3) *Mispointing results are w.r.t. the actual pointing of the ASAR. The ASAR has a known misalignment w.r.t. the satellite of : Elevation 0.025deg, Azimuth 0.018 deg, Normal 0.214 deg.*
4) *Pre-Launch Specification and budget values taken from R2*
5) *Mispointing algorithm supplies negative satellite axes Yaw and Pitch values. Sign inversion taken into account.*
6) *Budget values are for an uncalibrated LOS.*
7) *Mispointing results obtained after 0.3 deg. elevation correction, and on-board alignment matrix not taken into account. If 0.3 deg not considered then bias mispointing equals Roll = -0.121deg, Pitch = -0.258 deg., Yaw = -0.0479 deg.*

4.0 SPECIFIC REPORTING

4.1 MERIS

4.1.1 METHOD

The look direction of each pixel is characterised by a unit vector and two angles: Azimuth (across track direction) and Elevation (along track direction). Post-launch the actual look direction of a set of pixels can be determined using ground targets. These results can be compared with their pre-launch (expected) look directions to derive a mispointing estimate.

Pixel 'expected' look direction is simply derived from instrument on-ground alignment campaigns, while post-launch look direction determination is more difficult. Here, a MERIS Level-0 product (all 5 cameras together) is displayed to a user, who will select a ground target and specify its Latitude, Longitude and Height. Independently, the mispointing software will determine the pixel/camera viewing the target and, using the relevant restituted orbit with user inputs, calculate the pixel measured look direction Azimuth and Elevation angles.

The difference between measured and expected angles is a function of Roll, Pitch and Yaw attitude mispointing. So, taking many measurements across the full swath allows the attitude mispointing to be determined and the impact of noisy measurements reduced (each pixel size equals 1.149arc.min. -- 0.019 deg. -- and therefore, at the level of the mispointing seen, the measurements appear noisy). Figure 4.1.1-1 shows the user interface for selecting ground targets. The top right window displays the complete MERIS FOV, and shows The Netherlands, United Kingdom and Ireland from left to right (geographic north is at the bottom of the window). The left side window is a zoom of the white box in the top window, and a camera interface is clearly seen. The bottom right window is a zoom of the cursor position in the left-hand window.

4.1.1.1 GROUND TARGETS

The following table lists the WGS 84 latitude, longitude and height (m) of the ground targets used to derive the mispointing results. Due to difficulties in selecting the correct MERIS pixel, or poor target definition, some targets were removed prior to the least squares mispointing estimation, and therefore only fifty-five targets were finally used.

The targets were selected in Ireland, The United Kingdom and The Netherlands, since mapping data is readily available and conversions to the WGS 84 reference system possible.

Height (m)	Latitude (North)	Longitude (-ve= W)	Height	Latitude	Longitude	Height	Latitude	Longitude
80	57.8.19	-2.2.44	74	55.25.35	-5.7.8	39	52.45.0	5.7.31
80	57.7.45	-2.2.55	75	55.30.33	-5.4.51	44	52.37.12	5.7.41
100	56.37.40	-2.28.54	75	55.33.2	-5.4.59	43	52.28.8	5.4.4.
60.35	56.42.45	-2.26.67	100	55.37.9	-6.8.0	42	52.27.44	4.33.17
60	56.42.14	-2.27.14	42	53.00.12	4.47.33	43	52.28.4	4.33.58
51	56.27.50	-2.44.36	43	53.10.54	4.51.26	44	51.57.57	4.4.48
51	56.21.59	-2.49.17	49	53.18.6	5.5.50	43	51.59.4	4.5.52
50	56.21.51	-2.51.49	49	53.15.54	5.15.8	54	54.34.8	-8.22.12

61	56.16.45	-2.35.05	42	53.22.21	5.17.32	64	54.36.33	-8.35.37
61	56.11.30	-2.52.59	42	53.26.47	5.37.2	74	54.37.11	-8.40.52
49	55.40.23	-1.46.56	42	52.57.46	4.47.23	74	54.39.49	-8.49.37
74	55.37.44	-1.40.31	40	52.52.19	4.54.25	74	54.47.13	-8.33.11
74	55.37.38	-1.35.51	42	52.56.18	5.1.49	70	54.48.48	-8.33.36
74	55.19.18	-1.32.35	42	52.53.35	4.54.30	73	54.50.52	-8.27.22
74	55.11.12	-1.29.54	41	52.50.35	4.53.20	124	55.1.24	-8.32.33
74	55.4.14	-1.25.58	45	53.34.25	0.6.31	94	55.0.55	-8.33.43
58	54.41.37	-1.10.51	45	53.36.34	0.8.44	74	55.3.13	-8.25.52
53	54.38.47	-1.8.18	76	54.6.57	0.4.42	74	55.3.51	-8.22.57
54	54.25.50	-4.21.56	46	54.12.56	0.15.3	64	55.12.18	-8.9.45
105	54.2.43	-4.49.26	66	54.17.25	0.23.18			
60	54.3.17	-4.38.1	47	54.24.37	0.29.32			
104	54.8.35	-4.27.58	47	54.29.30	0.36.35			
115	55.17.36	-5.34.22	47	54.31.59	0.42.20			
65	55.26.5	-5.33.6	167	54.29.55	0.51.29			
70	55.34.18	-5.27.59	45	53.6.33	5.22.44			

4.1.1.2 PRE-CALIBRATION POINTING PERFORMANCE

Figure 4.1.1.2-1 below shows the CIA digital vector shoreline and a MERIS radiometric image plotted together. The radiometric image is derived from pre-launch alignment measurements taken on instrument and satellite levels. The match is good and therefore a qualitative assessment of this image confirms the small instrument pointing errors reported above.

4.1.1.3 POST CALIBRATION RESULTS

Figures 4.1.1.3-1a and 4.1.1.3-1b show results from a mispointing run. Note: Each straight line plotted is a linear regression of the relevant data and is included to better view the slope of the data.

Figures 4.1.1.3-1a shows the delta-azimuth (measured azimuth – expected azimuth) measurements (for a sub-set of targets) plotted against the MERIS swath. Delta-azimuth (dotted line plot) has a bias of approximately –4.10-4 rads (0.023 deg.), which gives directly the instrument Roll mispointing.

To confirm the sign and magnitude of the mispointing estimates, the delta-azimuth is corrected using the latest mispointing estimates and re-plotted. As expected, the corrected plot (solid line plot) moves to zero mean. However, the delta-azimuth slope remains unchanged, which indicates a small reduction in the MERIS FOV (approx. 0.3 of a pixel), which could be due to atmospheric refraction effects.

Figure 4.1.1.3-1b shows the corresponding delta-elevation measurements (dotted line plot). Here Yaw error dominates, as seen by the negative slope of the measurement data, but a small, negative pitch mispointing is also visible through the non-zero, positive mean value. Taking into account mispointing, both the slope and offset are reduced to nearly zero (solid line).

Figure 4.1.1.3-2 plots delta-azimuth and delta-elevation values for all fifty-five measurements used in the mispointing algorithm (with outlying measurements removed). Although it's not clear from the plot a significant number of measurements were taken at the edges of the MERIS FOV to improve YAW estimation.

The converters used to derive WGS-84 co-ordinates from map co-ordinates are located at:

The Netherlands: http://www.minvenw.nl/rws/mdi/plaatsbep/hoogte/coordinatecalculator.html

United Kingdom: http://www.gps.gov.uk/

Ireland: A converter on the web is not presently available (although there should be one in the near future), so a converter was added to the IECF using R3 & R4.


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1.6
Zoom Scale
Interpolation Style
Nearest Neighbor
Bilinear
Cursor Input Style
Button Press Only
Track Cursor
ADJUST COLOR TABLE
Press left button to zoom.
Done

Figure 4.1.1-1

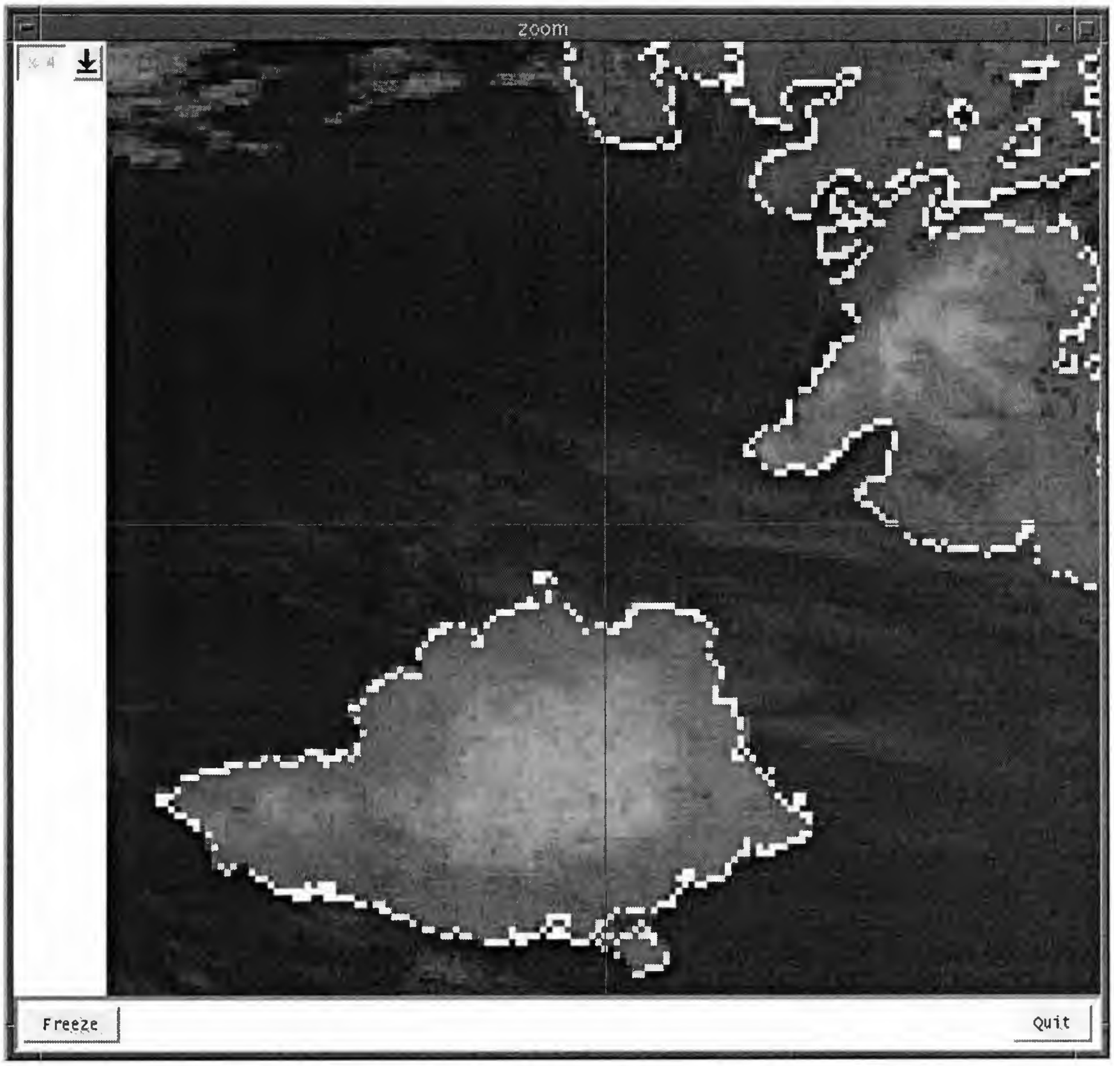

Figure 4.1.1.2-1

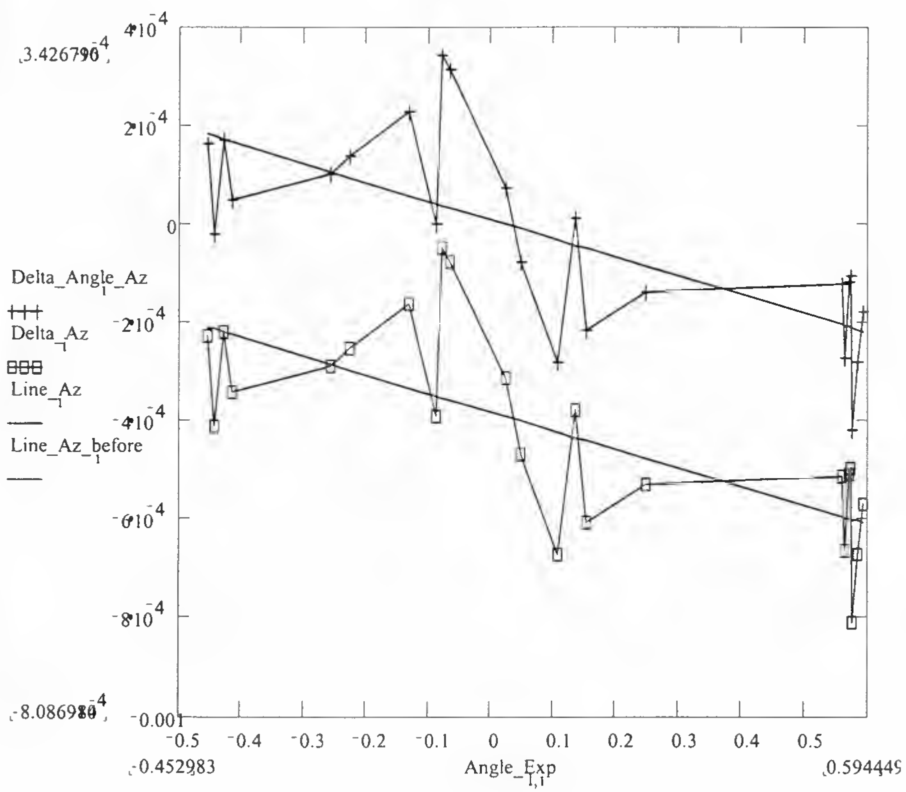

Figure 4.1.1.3-1a

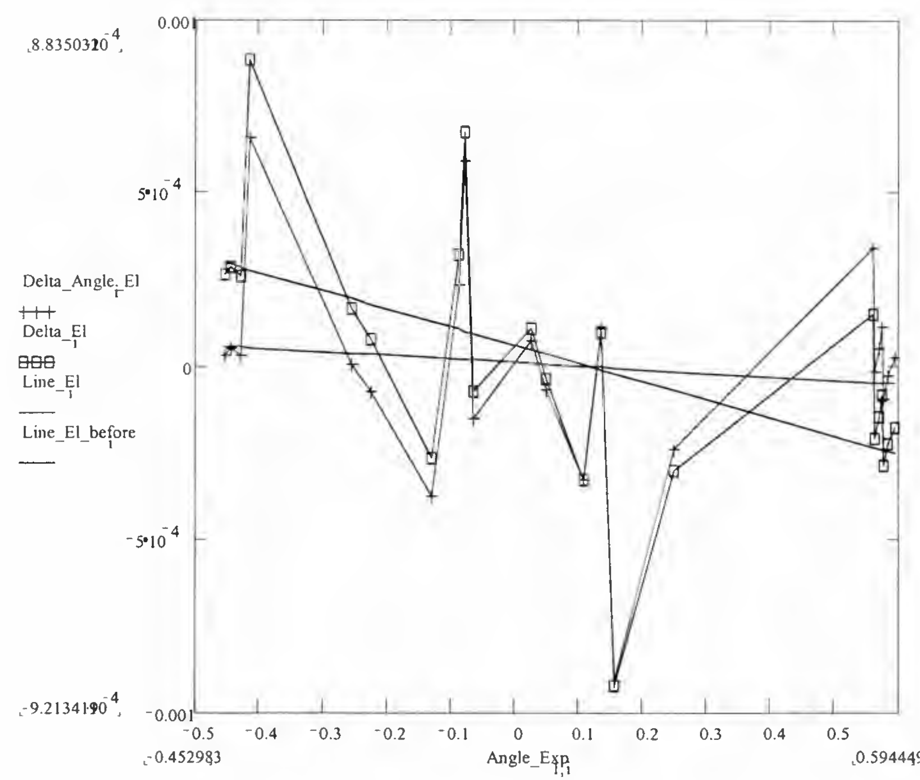

Figure 4.1.1.3-1b

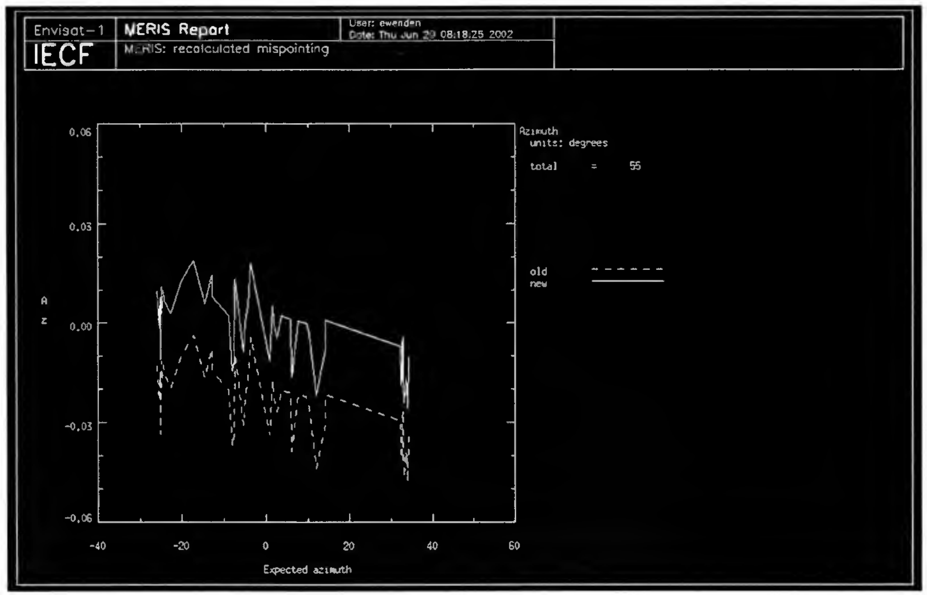

Figure 4.1.1.3-2a

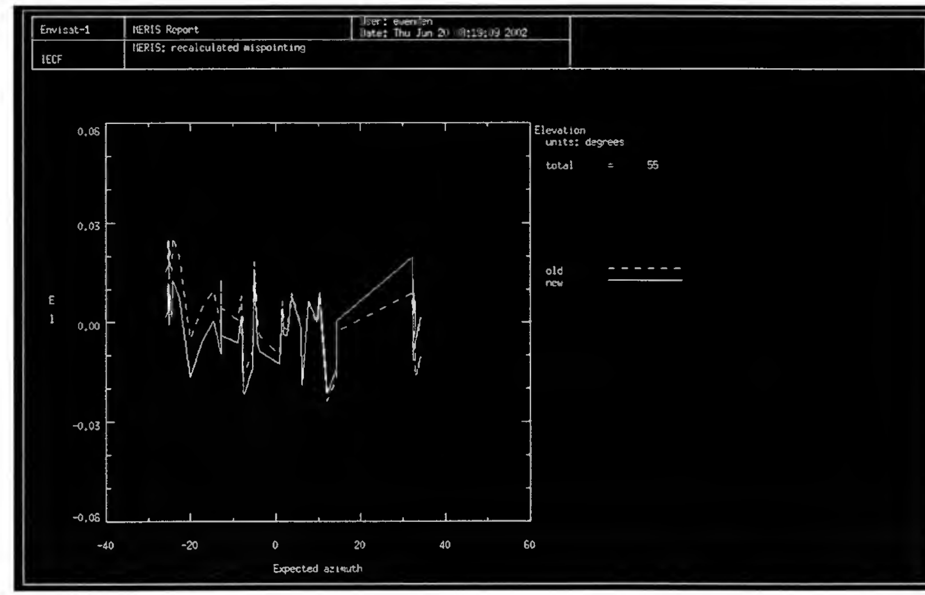

Figure 4.1.1.3-2b

4.2 ASAR

4.2.1 METHOD

ASAR measured doppler can be derived for various tie points within the radiated swath. The difference between measured doppler and expected doppler (including pre-launch instrument alignment) at the same tie points and at the same time within the orbit is known to be a function of Yaw/ Pitch instrument mispointing, satellite/ earth velocities and tie point position. Since the tie points and satellite/earth velocities are known the Yaw/ Pitch mispointing can be determined. To obtain separate Yaw and Pitch mispointing estimates, tie points are selected at Near and Far swaths. (Increasing the angular separation between Near and Far swaths improves estimation accuracy.) To separate mispointing bias and harmonic components measurements are taken around the orbit.

To date measurements were derived from Wave data operating with swaths 1 & 7 (widest swath). Expected doppler is derived using Envisat CFI's.

4.2.2 PRE- & POST CALIBRATION RESULTS

Figure 4.2.2-1 shows, for near and far swaths, the measured and expected doppler around the orbit, and is used to calculate the ASAR's pitch and yaw mispointing. The expected doppler is calculated taking into account the known alignment of the ASAR with respect to the satellite reference frame.

Figure 4.2.2-2a shows the same plot as Figure1, but this time the expected doppler is calculated taking into account the mispointing estimates. As can be seen the expected doppler is superimposed on the measured doppler. Figure 4.2.2-2b shows the difference between the measured and expected doppler taking into account mispointing. Both near and far swaths have nearly zero mean, and there is no definite structure (slope, harmonic) to the plots.

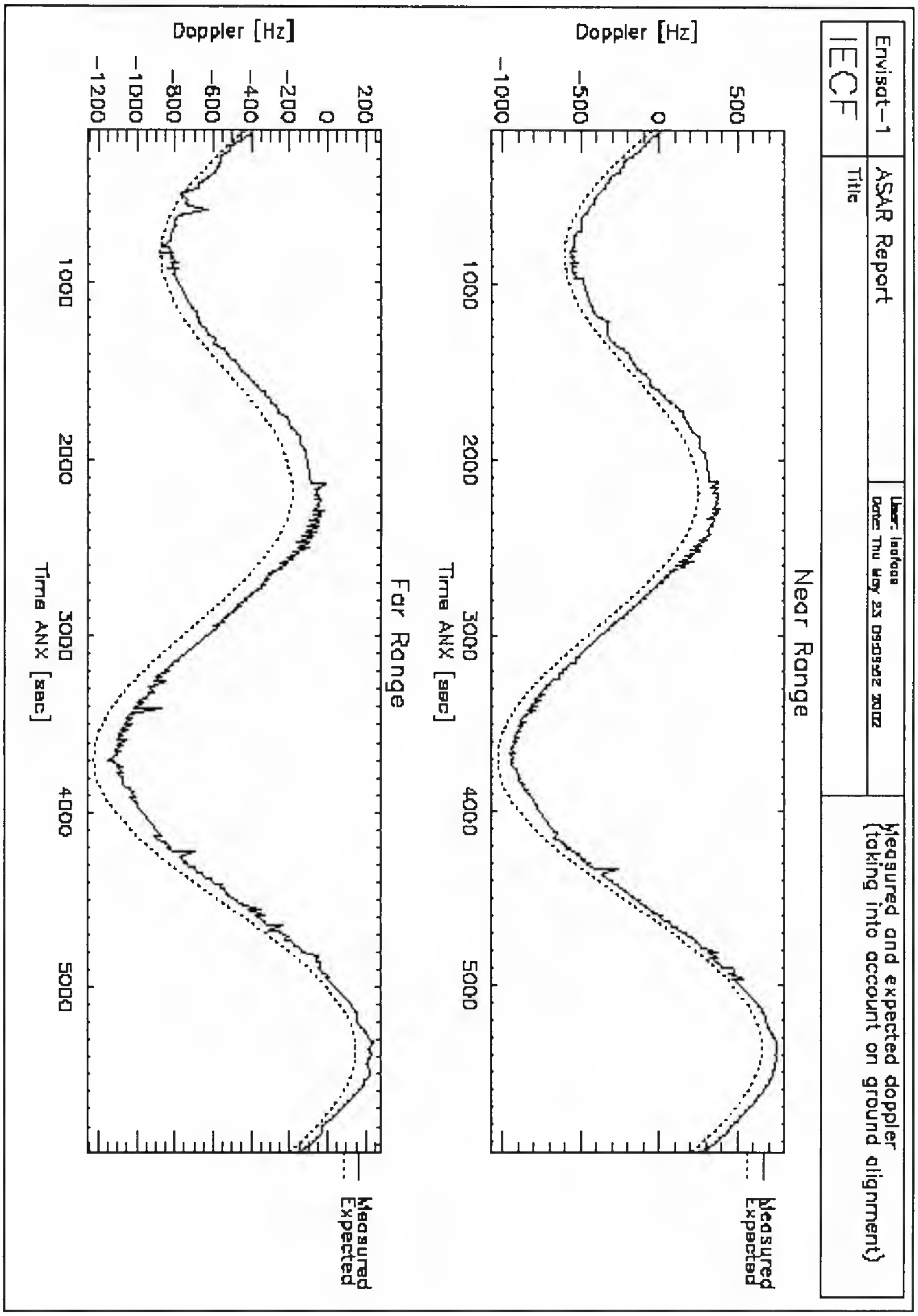

Figure 4.2.2-1 Pre-Calibration Results

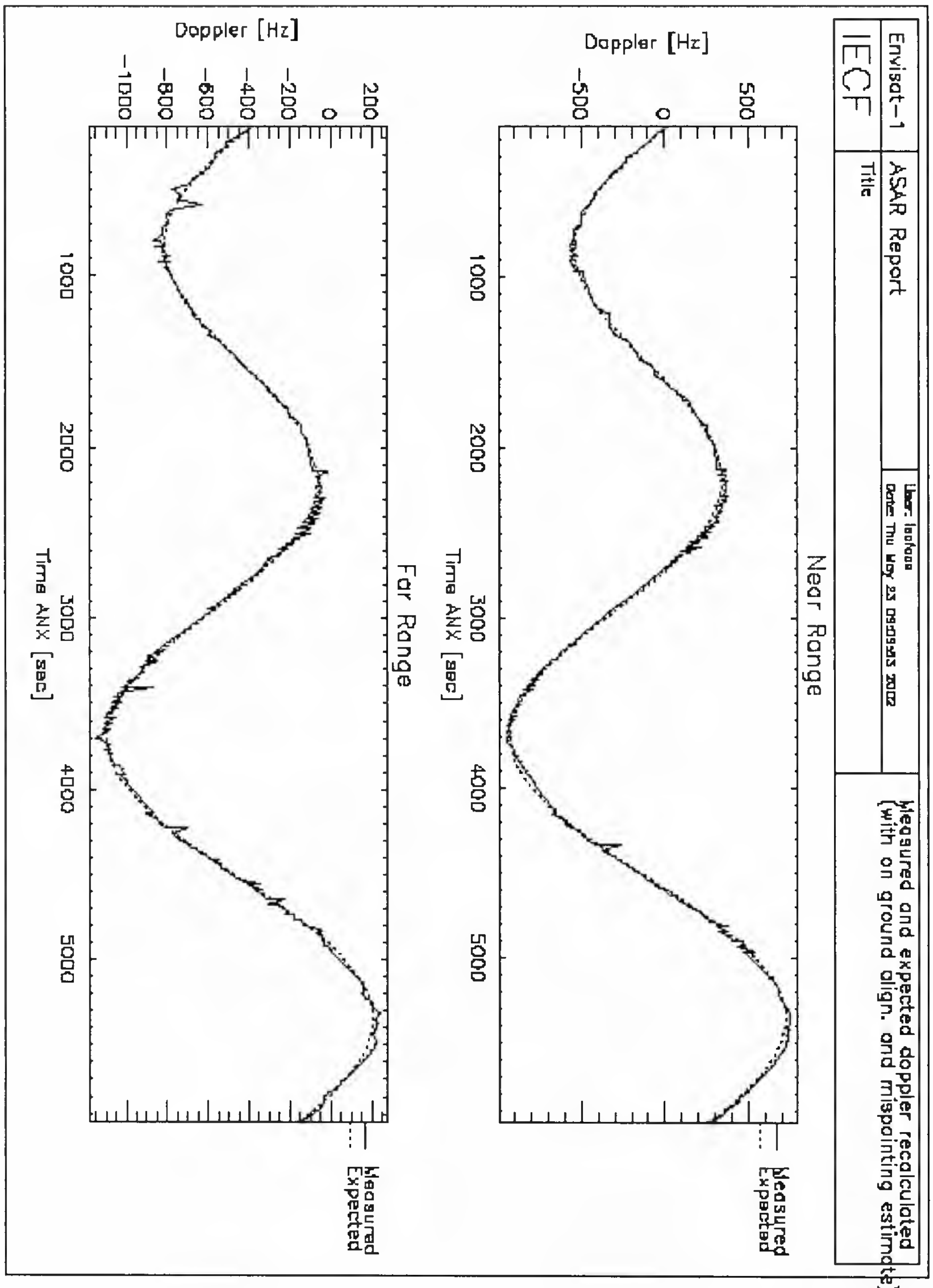

Figure 4.2.2-2a Post-Calibration Results

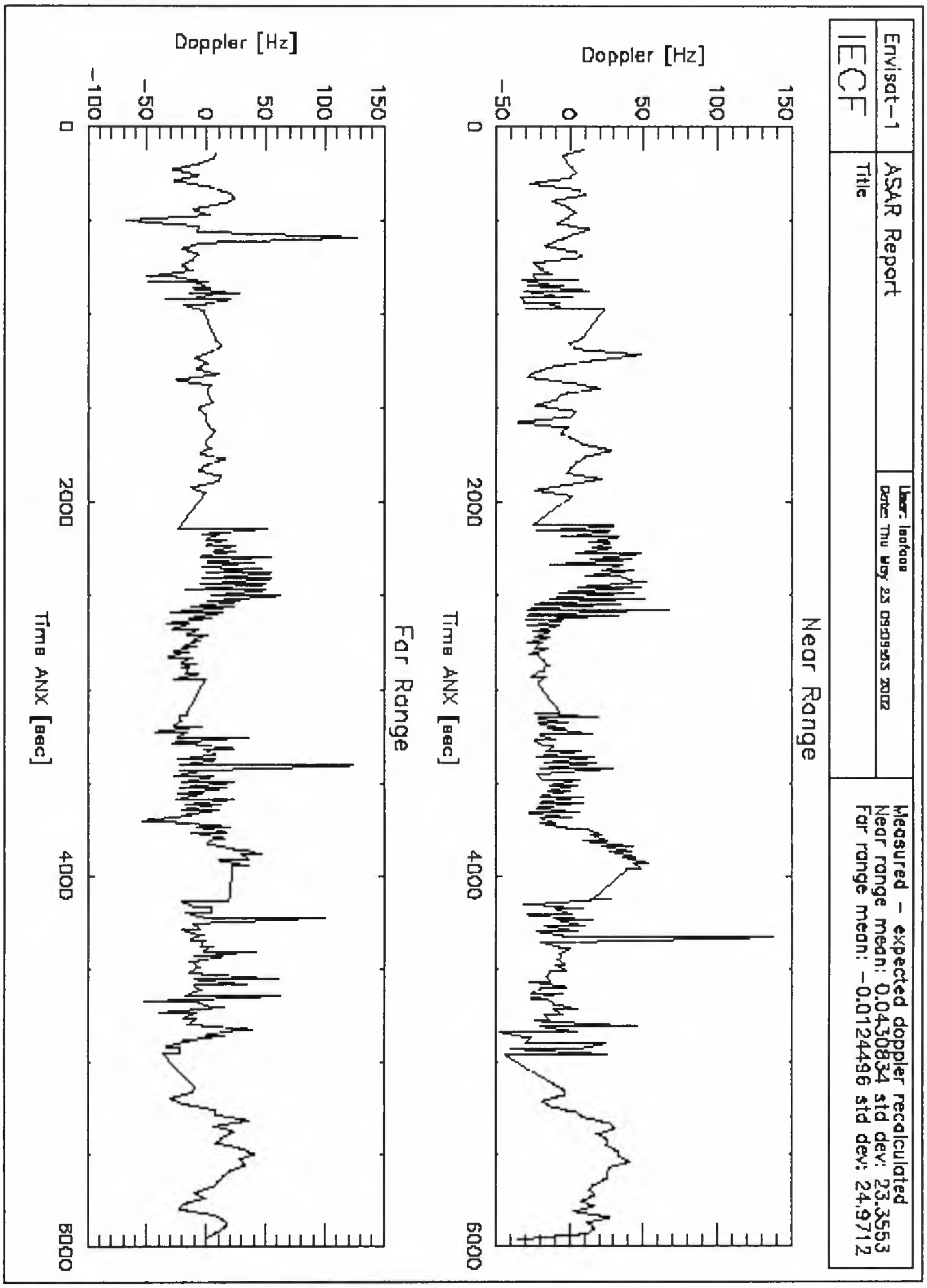

Figure 4.2.2-2b Post-Calibration Results

4.3 GOMOS

4.3.1 METHOD

The IFOV look direction is described by a unit vector and two angles: Azimuth and Elevation. When viewing a star the actual look direction of the IFOV is determined from instrument Steering Front Assembly telemetry and PGICD algorithms. Also, the expected look direction is calculated from pre-launch alignment measurements, star catalogue, star Id., orbit data and Envisat CFI's.

The difference between measured and expected azimuth and elevation angles is a function of Roll, Pitch and Yaw attitude mispointing. Measurements taken across the full azimuth range [-10 to +90 deg.] allows separation of Roll, Pitch and Yaw estimates, while measurements around the orbit allows bias and harmonic errors to be estimated separately.

4.3.2 RESULTS

Table 4.3.2-1 lists a typical sub-set of stars used in the mispointing algorithm. Azimuth and Elevation values are derived from ISPs and independently calculated using the CFI Target; the difference between ISP and Target data is directly related to in-orbit mispointing. Delta-Azimuth (ISP azimuth - Target Azimuth) and delta-elevation results are plotted in Figures 4.3.2-1a & b respectively.

Figure 4.3.2.1a demonstrates a near constant elevation error of approximately 0.3 deg over the azimuth range (upper graph). Following on-board correction (which is presently implemented within GOMOS), the delta-elevation error is significantly reduced, but a small offset of approximately 0.035 deg. still remains (lower graph). The on-board 0.3 deg. correction has slightly over-compensated for the initial large mispointing.

Delta-azimuth (which is a direct measure of instrument YAW mispointing and is unaffected by elevation correction) also has a residual offset of approximately 0.04 deg with a spread of +/- 0.025 deg. This offset might be due to the missing internal alignment matrix.

	UTC Time (ISP)	ABS	time since ID	RA (deg)	DEC (deg)	El (ISP)	AZ(ISP)	EL (target)	AZ(target)	Delta AZ	Delta EL
0	27-MAR-2002 04:55:54.929295	0	0	0	0	65.25258	4.195193	64.98061	4.133756	0.061437	0.271966
7	27-MAR-2002 04:57:18.732106	373	26	187.8268	-57.125	65.24144	8.586852	64.98125	8.521727	0.065125	0.260188
13	27-MAR-2002 05:06:14.366157	373	169	199.7616	-23.1833	65.1292	40.19681	64.84967	40.16846	0.028356	0.279532
12	27-MAR-2002 05:09:05.121487	373	163	187.4959	-16.5282	65.0833	32.05654	64.79828	32.02045	0.036092	0.285019
4	27-MAR-2002 05:10:57.581833	373	15	201.3283	-11.1733	65.02365	49.52647	64.74853	49.50344	0.023025	0.275124
6	27-MAR-2002 05:18:09.094767	373	22	152.1227	11.95654	65.26257	1.953721	64.9828	1.881181	0.07254	0.279769
10	27-MAR-2002 05:20:14.304007	373	51	155.0242	19.83085	65.21891	6.650482	64.93612	6.581835	0.068647	0.282788
1	27-MAR-2002 05:28:47.719862	373	3	213.9442	19.16915	65.78287	73.41916	65.5343	73.41223	0.006924	0.248569
9	27-MAR-2002 05:40:02.971746	373	49	38.10658	89.26553	65.01707	12.36479	64.739	12.29002	0.074774	0.278073
11	27-MAR-2002 05:48:27.388301	373	69	269.1636	51.48268	65.03676	50.57521	64.7636	50.5503	0.024913	0.273159
5	27-MAR-2002 05:53:01.354707	373	19	310.3696	45.28209	64.73019	26.88715	64.4519	26.834	0.053157	0.278293
2	27-MAR-2002 05:54:57.924669	373	5	279.2504	38.77997	64.71834	54.37276	64.45394	54.35188	0.020882	0.264399
14	27-MAR-2002 06:11:47.317873	373	188	305.2768	-14.7767	65.2807	25.36186	64.99771	25.31553	0.046339	0.282993
8	27-MAR-2002 06:18:18.924276	373	31	332.0821	-46.9514	65.07287	-8.68832	64.81211	-8.76976	0.081439	0.26076

Restituted Orbit File : AUX_FRO_AXVFOS20020329_225746_00000000_00000062_20020326_233300_20020329_021300.N1

Table 4.3.2-1

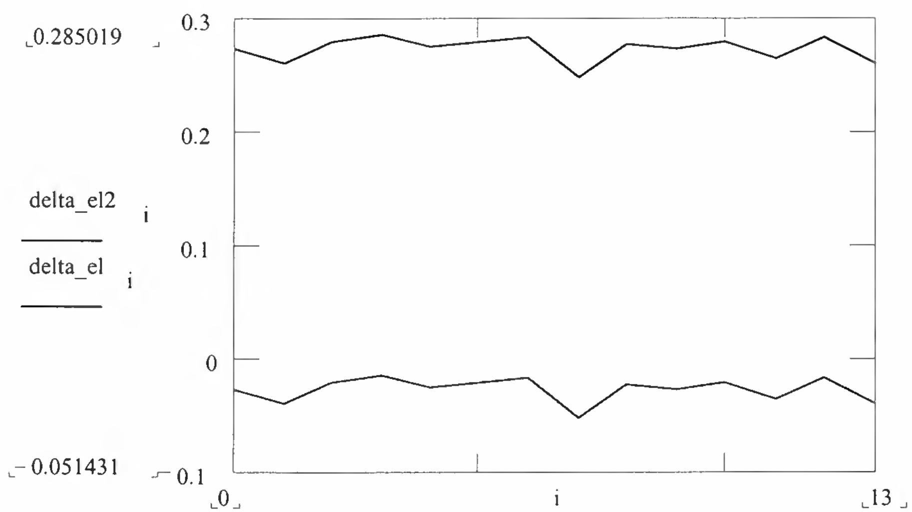

Figure 4.3.2-1a

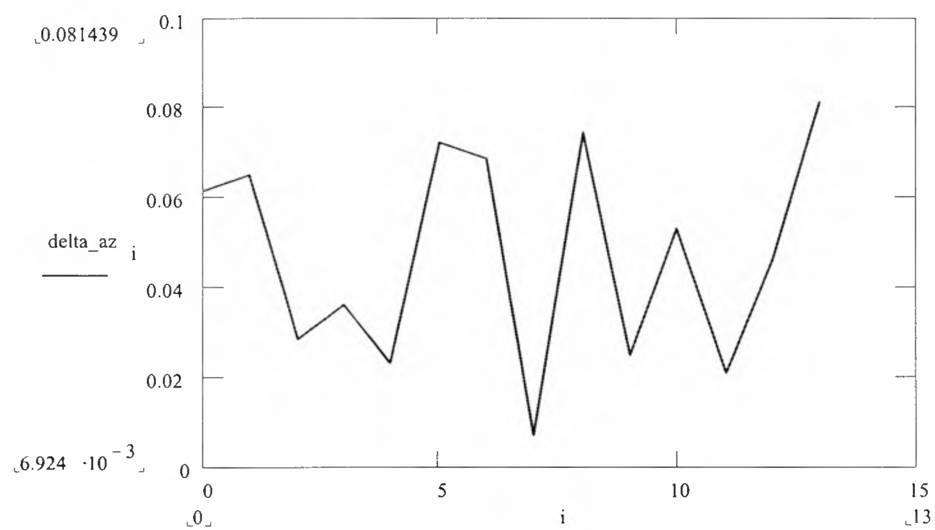

Figure 4.3.2-1b

4.4 MIPAS

4.4.1 METHOD

MIPAS uses a special instrument mode called LOS calibration, whereby the instrument's IFOV is positioned to scan across a star. The time when the star passes over the IFOV is derived using cross-correlation techniques and compared to the expected crossing time. The difference between measured and expected crossing times is related to the instrument's Roll and Pitch mispointing.

Taking measurements over the full azimuth range of the MIPAS FOV allows Roll and Pitch to be estimated separately.

Taking measurements around the orbit (when stars are available) allows the bias and harmonic errors to be estimated separately.

4.4.2 RESULTS

Only initial values are presently available, full results will be reported later.

4.5 AOCS & INSTRUMENT RESULTS COMPARISON

AOCS attitude determination has been independently undertaken by processing star tracker and gyro data, and therefore a comparison can be made between AOCS and instrument results. However, AOCS and instrument results are not identical since they don't measure the same thing. The AOCS results relate to the star tracker and gyros, but there are other mispointing errors between the AOCS and the instruments that AOCS processing cannot measure.

AOCS results do not observe/measure the following mispointing errors, which are detected by the instruments:

I. Star Tracker internal & external alignment errors

II. Launch Vibration

III. Platform Errors

- structural misalignment between the AOCS sensors and the instrument baseplate, due to:
    - 1 to 0 g effects
    - thermal distortions around the orbit, and on-ground to mean in-orbit thermal changes.
- Alignment measurement error between the platform and instrument.

IV. Instrument errors

- internal 1 to 0 g effect

- Instrument thermal distortions around the orbit, and on-ground to mean in-orbit thermal changes
- Instrument internal alignment errors (optical path, mirror pointing errors, etc.)
- Mechanism pointing errors (encoder meas. errors, etc.)

V. Errors arising from the mispointing method (PDS ASAR doppler calculation, measurement quantization, MERIS pixel size, encoder meas. error, etc)

Individually these errors are small, but collectively they might combine to give a reasonable mispointing. So, it's not inconceivable that the AOCS estimates a pitch mispointing of approximately 0.010deg., while the instruments give –0.002 (MERIS), 0.025 (MIPAS) and -0.015 (ASAR, in satellite axes.)

5.0 CONCLUSION

From the instrument mispointing results obtained, it's confirmed that MERIS and ASAR post-launch mispointing are well within specification.

On the other hand, GOMOS was found to have a significant elevation error, primarily due to a gravity compensation device resident within the instrument. Following on-board correction by 0.3 deg. the IFOV has the residual mispointing reported above. Unfortunately, this residual mispointing cannot be linked to either instrument or platform pointing performance since the 0.3 deg. correction was selected to compensate for the total mispointing (due to gravity compensation device, platform and instrument errors).

MIPAS mispointing analysis is still on-going and will be reported in the future. However, initial results appear comparable to MERIS and ASAR.

Comparable mispointing results are obtained from independent processing of AOCS sensor data.

Regular instrument mispointing can be undertaken, but the instrument's scientific mission might have to be interrupted to obtain measurements with specific modes/swaths or orbital segments. However, since ASAR, GOMOS and MERIS have excellent pointing margins, and since pointing knowledge has improved (to support instrument commanding or ground processing), it's believed unnecessary to repeat a pointing characterisation. During routine operations, for orbits containing a sufficient number of stars, MIPAS will characterise its mispointing and mission time outage has been allowed for this.